Design and Construction Aspects of the Largest "Pile Curtain" Retaining Structure Built in the Tropical Soil of the Brazilian Central Area

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Abstract

This paper presents unpublished data on the largest excavation and retaining structure of the "pile curtain" type already constructed in the Center of Brazil, more specifically at the city of Brasília. This city is characterized by having a tropical, unsaturated, collapsible sandy clay soil known as the Brasília "porous" clay. These soil characteristics are reproduced, with some differences, in most areas of the Brazilian Central Plateau. Hence, the paper briefly discusses about project details and presents the simplified design approach adopted for the retaining structure, that was carried out with the Geofine (www.fine.cz) software package. This case history is also under scrutiny of an on-going research thesis, which aims the interpretation of its instrumented results and the establishment of more refined numerical analyses.

Introduction

The Brazilian capital, Brasília, is a pre-designed city located within the "Federal District", in the center of Brazil. It was built in the early 60's to house the main Governmental administrative institutions and its public employees. It has increased (and it is still expanding) four times more than what was

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initially forecasted, enabling the practical use of distinct design techniques for excavations (and deep foundation) within the several construction sites.

Hence, in 1995 the University of Brasília started a major research project in the foundation area, in order to enhance the knowledge on the behavior of the distinct foundation types that are founded in the predominant (tropical, unsaturated) subsoil of the Federal District. Some years later, in the "new century", this emphasis was also oriented towards the behavior and design of large excavation and retaining walls, predominantly of the "pile curtain" type. These walls are constructed by adding together, side-by-side or with some space in between, excavated bored or CFA piles. Once piles are placed, the excavation process in front of the wall can be started. This is accomplished in sequence, according to designed excavation levels, excavation trenches, and the required (in most cases) inclusion of anchored bars or passive nails. The latter ones are largely used to reduce costs in the region. With this same purpose, it is common now the use of "unsaturated" soil parameters in design, and the construction of provisory retaining walls to "hold in place" solely during the region's dry season (April to September).

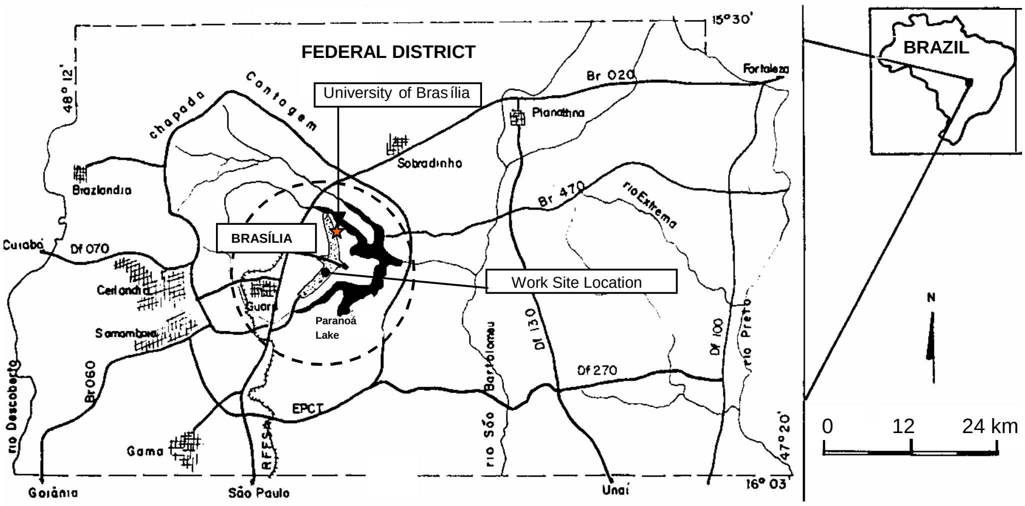
Nevertheless, knowledge of the behavior of such structures has not advanced so far within the particular conditions of the city, with its localized wet and dry seasons, unsaturated soil conditions, and meta-stable soil structure (collapsible soil). This is indeed related to the lack of structures of this type just some few years ago, and the small amount of research focused in this theme. On the other hand, Brasília has already experienced bold constructions of retaining structures of this type, as the one started this year in the South Commercial Sector of this city. This particular work is composed of ϕ 50 cm bored piles spaced at an avg. 1.1 m center-by-center distance, with total lengths varying from 14 to 18 m, which includes a fixed 4m-embedment depth. Several sub sections for each face have been designed, and are supported by 4 or 5 lines of anchorage beams with passive nails (using single or double ϕ 25 mm steel bars). The max excavation depth was around 14 m, which is considered to be the major retaining structure of this type already constructed in the central area of Brazil.

The paper, therefore, explores this case history, briefly presenting its location and the geotechnical conditions of the site, and discussing on some of the major design and construction details of the retaining work. Initial horizontal displacement results from one of the faces, acquired by the on going thesis, are also given.

Site Location and Geotechnical Characteristics

Brasília and the Federal District are located in the Central Plateau of Brazil, as presented in Figure 1. This district has a total area of 5814 km^2 and is limited in the north by the 15°30' parallel and in the south by the 16°03' parallel. The University of Brasília (UnB) campus is located within the city of Brasília in its "north wing", portrayed in this figure by an "airplane" shape like form. The working site of the retaining structure is also located in this same city, however at its "South Wing" (commercial sector), as portrayed in Figure 1.

Within the Federal District extensive areas (more than 80 % of the total area) are covered by a weathered latosoil of the tertiary-quaternary age. This latosoil has been extensively subjected to a laterization process and it presents a variable thickness throughout the District, varying from few centimeters to around 40 meters. There is a predominance of the clay mineral caulinite, and oxides and hydroxides of iron and aluminum. The variability of the characteristics of this latosoil depends on several factors, such as the topography, the vegetal cover, and the parent rock. In localized points of the Federal District the top latosoil overlays a saprolitic/residual soil with a strong anisotropic mechanical behavior and high (SPT) penetration resistance,



which originated from a weathered, folded and foliate slate, the typical parent rock of the region. In other points this latosoil overlays a thick layer of metamorphic rocks (sandstones, claystones, etc.). The former case is the case found in the location of the retaining structure. Indeed, pile excavation for the pile curtain structure has advanced until it approached, and started penetrating, the local slate saprolite strata. Thus, the base of the piles was founded on hard silty clay with SPT blow counts that were in average higher than 30.

Figure 1. Excavation and working site location.

The superficial latosoil is locally known as the Brasília "porous" clay, being geotechnically constituted by sandy clay with traces of silt, forming a lateritic horizon of low unit weight and high void ratio, as well as an extremely high coefficient of collapse. Although these characteristics vary from site to site at this city, its main geotechnical characteristics are generally similar. These characteristics have already been published elsewhere (Cunha et al. 1999) for the University of Brasília Foundation and In Situ Testing Research Site, and are presented in Table 1 as an example of the range of values typically found for this clay.

In the particular area occupied by the University of Brasilia Experimental Site the porous clay has a thickness of ≈ 8 m, followed by a transition zone overlying the saprolitic/residual soil of slate, with no water level. These characteristics are similar to the working site location, with difference of a thicker porous clay layer in this site.

The geotechnical parameters displayed in this Table 1 were obtained by a comprehensive laboratory testing program carried out by previous and simultaneous research projects of the University of Brasília. Conventional characterization tests were performed together with more sophisticated tests, as double oedometer and collapse tests, triaxial K0 and triaxial CK0D tests (both at natural moisture content), permeability tests and direct shear tests with the samples under distinct orientations.

Some of the laboratory tests were carried out with undisturbed block samples taken from an inspection well dug at the research site. These samples were taken at 3, 6 and 9 m below soil surface, and were tested in the Furnas laboratory through a joint research association with the University of Brasília.

Table 1. Approximate Parameters of the Porous Clay.

Parameter Values	Units	Range of	
Sand percentage	%	12-27	
Silt percentage	%	8-36	
Clay percentage	%	80-37	
Moisture content	%	20-34	
Nat. unit weight	kN/m^3	17-19	
Degree of saturation	%	50-86	
Void ratio	--	1.0-2.0	
Liquid limit	%	25-78	
Plasticity limit	%	20-34	
Plasticity index	%	5-44	
Young Modulus	MPa	2-14	
Drained Cohesion	kPa	10-34	
Drained Friction angle		degrees	25-33
Coefficient of Collapse		%	0-12
Coefficient of earth pressure at rest	--	0.4-0.6	
Coefficient of permeability	cm/s	10^{-6}-10^{-3}	

Marchetti dilatometer tests (DMT) and standard penetration tests (SPT) were also carried out at the University of Brasília Experimental site in order to obtain pioneering “raw” data for DMT test in this particular site, as well as to better characterize it. These test results are presented in Figure 2 and represent, in average, “typical” results for in situ tests in the laterized porous superficial Brasília clay. It is given herein as an example to better illustrate this clay’s characteristics to the reader.

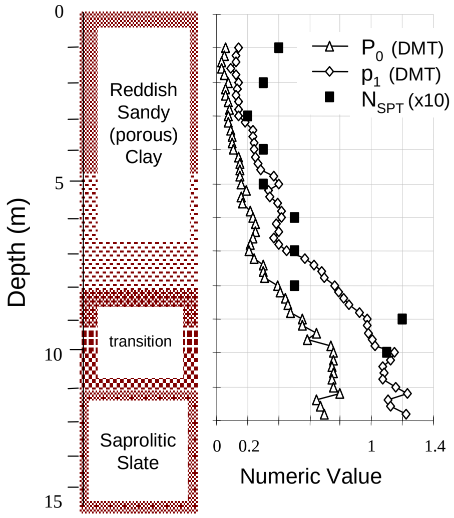


Figure 2. Typical DMT and SPT results for the Univ. of Brasília research site

Retaining Structure Characteristics

Some of the details of this structure have already been presented before. It was basically designed to support, and keep open, a square excavation area of around 50 versus 60 m. Given the average excavation depth of 12m, this represents an excavation pit of approximately 36000 m^3.

Figure 3 presents the four faces of the excavation, and the square arrangement of the retaining structure. Each face of the retaining structure was designed with distinct sub sections, or sub faces, to take into account the variability of the terrain behind it, and the variable level of the slabs designed by the building’s architect. As commented before, the slabs of the building will hold in place the retaining structure, once the building is constructed. Hence, slab position and levels oriented the location of the anchored beams of the structure. For instance, Figure 4 presents the details of the “South” face, where it can be noticed the inclination of the four (V1 to V4) beams at sub faces D1 to E. The reason of this inclination is related to the fact that the building will serve as a commercial parking lot, requiring many driving ramps.

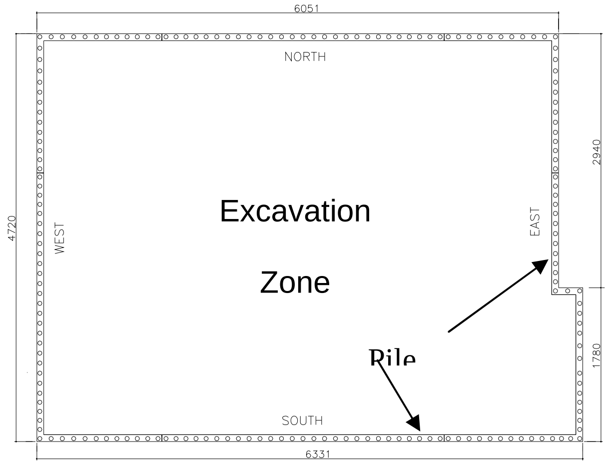


Figure 3. Overview of the retaining structure and its four faces (values in cm)

It is also noticed that single and double Brazilian CA50B corrugated steel bars were simultaneously adopted as anchoring (passive) nails respectively for beams (V1&2) and (V3&4). Note that beam V3 only started to have double bars close to sub face E, where the level of terrain behind the structure reached its maximum height. This particular design allowed savings in the construction of the retaining structure, by tailoring it to site characteristics, besides of providing firm structural indentations (anchorage beams) to sustain the slabs of the building.

Passive nails were used to reduce the costs of the structure, although it was known that it could induce much higher top horizontal structure displacements than by using conventional pre-stressed injected anchoring bars. The nails were constructed with an initial (manual) 8” dia. borehole tilted to an 15° angle. Manual excavation is possible within the porous superficial and weak clay of Brasília. This procedure was sequentially followed by bar(s) insertion, cement mortar filling of the borehole and, finally, construction of the anchorage beam. The single bar nails were designed for a geotechnical and structural working load of 150 kN, whereas the double bar ones for twice this value.

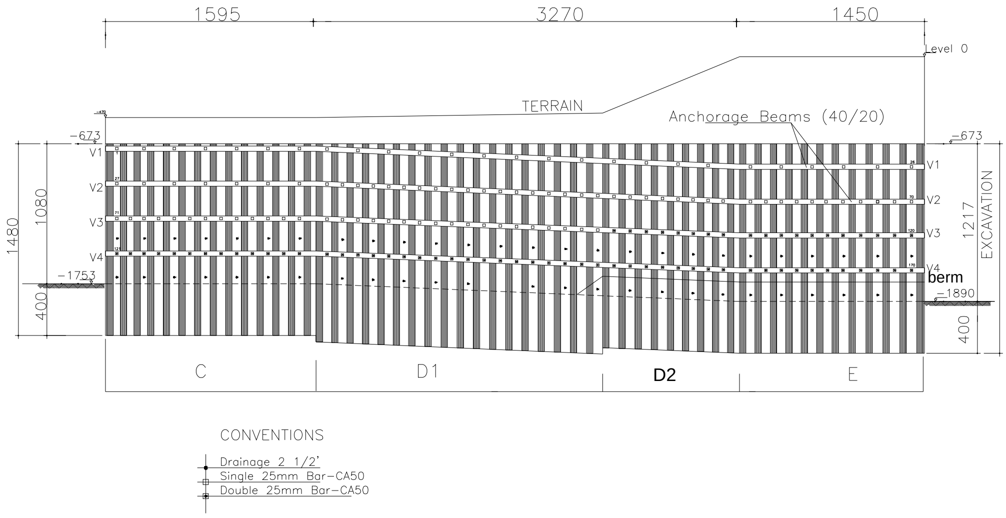


Figure 4. Details of “South” face of the retaining structure (values in cm)

Figure 5 presents typical details of the nail and beam. It shall be noticed that the nails were executed “in between” the piles, i.e., in the open space (around 50 cm) between the faces of the bored piles, where the soil was retained by horizontal arching effects.

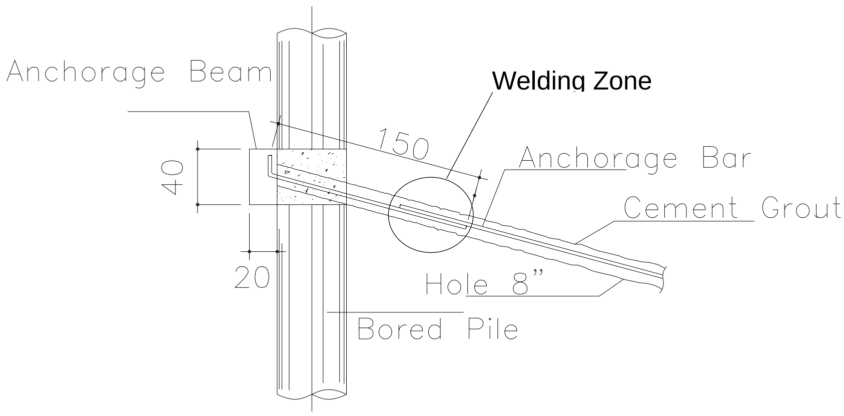


Figure 5. Details of anchorage beam, passive nail and bored pile

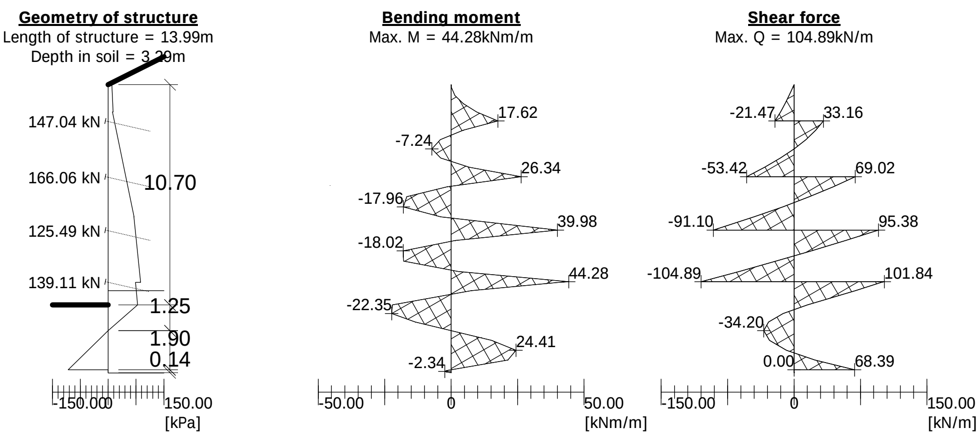
The nails had distinct lengths along wall depth. In general, high levels (close to surface) nails had longer lengths than low level ones (close to excavation base). Their length was based on the theoretical active failure plane mobilized behind the wall, and the necessity of a sufficient length to withstand the calculated tensions. Thus, as an example, single nail bars from the South face had total lengths of 10, 8 and 7 m respectively for V1, V2 and V3 beams. On the other hand, all double bars where designed for a minimum length of 12 m, independently of their position (generally close to excavation base). For the South face (see Figure 4) this was the length for some of the nails from V3 beam, and all V4 beam nails.

Design Characteristics

The wall was designed and calculated by the University of Brasília, and further detailed in blueprints by a private company of the region (Embre Engineering Ltd., working in partnership with the university). The computational software Geofine version 4, “sheeting design” module, was used in the final design. Given the lack of tradition and fundamental experience in numerical analyses with this particular structure and soil conditions, a simple classical modified “free earth support” method, built within this module, was used in the calculations.

Besides, in order to obtain more experience with this engineering work, a MSc thesis (Medeiros 2005) started in the Geotechnical Grad Program of the University of Brasília, with emphasis in the instrumentation (horizontal displacement) and numerical analysis of this structure. This will undoubtedly shed some light in future projects of this type, in which modern (numerical) simulation tools can be used under better known safety conditions.

The design took into consideration the unsaturated soil conditions of the dry season that prevailed during structure construction. Hence, effective cohesions as high as 15 kPa were adopted for some of the (three) soil layers idealized by the Geofine software. This is considered high for Brasília clay, where (“wet”) values around 5 kPa can be observed with inundated samples in direct shear tests. Suction was also considered to act and enhance the adherence between the nail (cement mortar) and its surrounding soil. Thus, Figure 6 exemplifies the output of this software, for D2&E sub faces of the



structure. Note a lower excavation depth (10.7m), given by the introduction of an earth berm in front of these sub faces (see Figure 4).

Figure 6. Geofine output values for D2&E South face – without safety factors

This wall was designed to be provisory, i.e. to hold in place until the slabs of the commercial building, which was projected in the excavated area, definitively fix it. According to the forecasted chronogram, this phase of the construction would finish before the wet season of the region. Therefore, the support system was not designed to statically withstand during the wet season where, as it is hypothesized from the lab. results, the soil cohesion would drop to values as low as 5 kPa. This condition was strongly emphasized to site contractor, since, in order to achieve maximum saving, some risk was indeed involved. Fortunately enough, at present stage (wet season), the wall has already been partly fixed by the slabs of the construction, and risk has been fully minimized or extinguished. Nevertheless, if had been necessary, a (secret, we may say now) contingency plan was devised by wall constructor, which was to reinforce it via introduction of complementary nails as soon as soil plastification, and failure processes, started to take place.

Although more research is required, these design parameters as well as all others adopted herein have proved to be suitable, in *engineering* terms, for site and structure conditions. For instance, at completion of the building's excavation no structural or geotechnical problem had been noticed. Indeed, initial instrumentation results from Medeiros 2005 showed very low levels ($\leq$ 3mm) of horizontal displacements on top of the West face of the wall. This value represents, for this face, a relative displacement (Δ/H) of approximately 0.03%.

Since this is and on-going thesis, this is the only result which can be provided so far. Nevertheless it is (unexpectedly) of good characteristics and compare very well with the few other data available in Brazil. For instance, for the São Paulo city underground construction, Massad 2005 reports relative displacements in the range of 0.04 to 0.05%, valid for the weathered sedimentary and tropical soil (tertiary formation) deposit from this city.

Conclusions

The major conclusions of the present case history are:

1. If some risk is allowed, it is possible to considerably reduce wall construction costs in unsaturated tropical soil regions with well-defined and distinct (dry and wet) seasons, simply by designing it to solely withstand during the dry season;
2. A simple classical modified "free earth support" method has proven to be enough to design bold support wall systems in the studied region;
3. It is possible to obtain satisfactory design solutions by combining academy and industry efforts and interests. This will also lead to (future) better and even safer designs in areas with "non-classical" tropical soils.

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